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Water Chemistry of Rocky Mountain Front Range Aquatic Ecosystems

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Abstract: A study of the water chemistry of Colorado Rocky Mountain Front Range alpine/subalpine lakes and streams in wilderness ecosystems was conducted during the summer of 1995 by the USDA Forest Service Arapaho and Roosevelt National Forests and Rocky Mountain Forest and Range Experiment Station, and the University of Colorado Institute of Alpine and Arctic Research. Data were collected to examine the water chemistry of Front Range high-elevation lakes and their sensitivity to atmospheric deposition, particularly nitrogen saturation. Water chemistry data from synoptic surveys of high-elevation lakes in wilderness areas of other National Forests in Colorado are also included in this report. Because of the extent, uniqueness, and potential value of the data collected, the entire water chemistry data base including over 265 samples from more than 130 lakes and streams is presented. Preliminary data examination indicates that many lakes have detectible nitrate concentrations, nitrate concentrations are higher early in the season and decrease as the season progresses, and inlets often have higher nitrate concentrations than outlets. Detailed data analysis and interpretation, its relationship to landscape characteristics, and the implications for ecosystem response and management will be presented by the authors in subsequent manuscripts in preparation.

Keywords: water chemistry, alpine/subalpine lakes and streams, atmospheric deposition, nitrogen saturation, ecosystems, aquatic

Cover photo: Upper Lake in Indian Peaks Wilderness

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INTRODUCTION

Aquatic ecosystems are more susceptible and respond more rapidly to direct input of atmospheric deposition than terrestrial ecosystems (Irving 1991). Atmospheric deposition in the Eastern United States and its affect on aquatic ecosystems are well documented (Irving 1991); however, little is known about the extent or effects of atmospheric deposition on lakes and streams in the Western United States.

Lakes and streams that are most susceptible to acidic deposition have low concentrations of anions and cations. This results in low acid neutralizing capacity (ANC) and reduced ability to buffer acidic input. Low ANC lakes are often associated with catchments that have little or poorly developed soils, which reduces soil chemical alteration of precipitation or snowmelt before it enters lakes and streams. Lakes and streams with low ANC and catchments with little soil development are often located at high-elevation recently glaciated sites that have a large percentage of exposed bedrock. Low ANC also indicates that reduced amounts of nutrients are available for aquatic biomass production. Nitrate and phosphate are the nutrients that most frequently limit productivity; therefore, aquatic ecosystems within such catchments often have small biomass amounts.

Snowmelt dominates the hydrologic cycle early in the melt season. Large concentrations of nitrates are eluted from the snowpack with the initial melt; some of this enters surface waters directly. However, unless considerable amounts of bedrock are exposed, much of the snowmelt enters talus or soils where biological and chemical alteration rapidly occurs (Campbell et al. 1995). Snowmelt may enter storage pools and runoff may result from the outflow of water from these pools (Kendall et al. 1995).

This study concentrated on the Front Range of Colorado. Weber (1976) defines Colorado's Front Range as the range of mountains visible when approaching Denver from the east; specifically, from Pike's Peak north along the Continental Divide through Rocky Mountain National Park. Others designate the Front Range as the region from the Colorado and Wyoming border south to the Arkansas River (Arno and Hammerly 1984). Although this study included samples from lakes as far south as the Sangre de Christo Range and north into the southeastern corner of Wyoming, the area of study in this report is referenced as the Front Range.

OBJECTIVES

This study was a synoptic survey of lake water chemistry, especially nitrate, in the mountainous areas east of the Colorado Continental Divide and in southeastern Wyoming that are exposed to increasing atmospheric emissions. A goal was to include as many high-elevation lakes as possible within a specific sampling time window. For a subsample of selected catchments in the Arapaho and Roosevelt National Forests, the study examined differences between lake inlet and outlet streams, and early season and late season sampling dates. Analyses of relationships between lake chemistry and landscape characteristics, such as soil type, geology, vegetation, terrain, watershed size, lake surface area, and elevation, are not included in this report.

WESTERN UNITED STATES LAKE CHEMISTRY

Few data are available concerning the current susceptibility to acidification or nitrogen saturation of lakes in the Western United States. Only one major survey of lake susceptibility to acidification in the Western United States has been conducted (Eilers et al. 1987, Landers et al. 1987). This one-time sampling identified lakes, generally at high elevations with poorly developed soils, that might be susceptible to increases in atmospheric deposition because of their low buffering capacity.

Among the hundreds of lakes sampled in the 1985 survey (Eilers et al. 1987, Landers et al. 1987) only about 130 were in Colorado and less than a third of these were from wilderness areas sampled in the current study. The Front Range urban corridor of Colorado is experiencing rapid growth and increased nitrogen and sulfur oxide emissions that contribute to nitrate and sulfate atmospheric deposition in the adjacent mountainous areas. In addition, coal fired power plants in Western Colorado emit nitrates and sulfates that contribute to deposition in Front Range ecosystems.

NITROGEN DEPOSITION

Productivity is limited by the amount of nitrate available for growth in many high-elevation aquatic ecosystems in the Western United States (Williams et al. 1996). Nitrate available for growth and productivity depends upon nitrate input from deposition, weathering, catchment storage, or biomass decomposition. Even small changes in the nitrate levels of aquatic ecosystems can result in large alterations in species assemblages and phytoplankton abundance. If phytoplankton do not use all available nitrate to increase productivity, nitrates are exported and the system is considered saturated (Williams et al. 1996). However, some lakes may be phosphate limited due to a low natural supply of phosphate. Nitrogen export in these lakes may indicate a lack of phosphate rather than an excess of nitrogen (Morris and Lewis 1988).

Nitrogen export may represent the seasonal nature of the ionic pulse of nitrate or the inability of the biomass to use nitrate when it is rapidly flushed through the system. Frequent monitoring of water chemistry and phytoplankton populations throughout the season is necessary to determine the interaction between phosphate, nitrate, and biota, and then decide whether nitrate is exported because low phosphate levels limit productivity or because input rates are so high that complete use is impossible. Excess nitrate in aquatic systems also occurs from decomposition when populations decline after phytoplankton blooms, a natural phenomena occurring during cyclic growth patterns in aquatic systems. Excess nitrate can also occur in surface waters from a sudden lake turnover after strong wind or heavy precipitation.

Although one source of excess nitrogen is deposition input, soil and biological processes also contribute to excess nitrogen in surface waters. Nitrogen is available from soils but most high-elevation sites along Colorado's Front Range have relatively young, minimally developed soils; nitrate availability from these soils is low. Nitrates in soils are not tightly bound on ion exchange sites. Nitrogen input in high-elevation ecosystems with limited soil development is primarily from atmospheric wet deposition, which is from high amounts of precipitation. In addition, large amounts of nitrogen are temporarily stored in the winter snowpack (Bowman 1992) from wet and dry deposition and become available for biotic use with snowmelt.

Although nitrogen input from stream water and snowmelt is an important source of nitrate for biomass productivity in high-elevation lakes, there are alternative sources of nitrate in surface waters. Monitoring aquatic biomass could explain alternative sources of nitrate in Rocky Mountain aquatic ecosystems. This information is unavailable from monitoring water chemistry only. Certain blue-green algae, such as *Anabaena* spp and *Nostoc* spp, fix nitrogen and add nitrate to the system. Algal blooms also influence nitrate levels. During these periods of rapid growth, nitrate concentrations approach zero as all available nitrate is used. However, when these populations die, large amounts of nitrate are released into the water independent of nitrate input from streamflow or snowmelt. Stratification or mixing of lakes also influences the quantity of nitrates available for phytoplankton growth. This occurs as nitrates at deeper levels become unavailable to surface algal populations with stratification or become available with mixing. Mixing of a stratified lake depends on basin characteristics and lake size and depth, and can be caused by sudden, local meteorological changes.

Temporal variation exists in the concentration of lake nutrients as import and export of nutrients change. Snowmelt flowpaths and processes, groundwater storage and retention, weathering, and soil processes are involved in nitrate concentration changes in surface waters. Interpretation of water chemistry data must consider naturally occurring biotic, weathering, or temporal changes in the nitrate content of lakes and in other possible sources of nitrogen in surface waters. Excess nitrate concentrations can also occur without excess input in Front Range aquatic systems limited by phosphorus (Morris and Lewis 1988).

Excess nitrogen can have subtle affects before exportation including increase in productivity or changes in terrestrial and aquatic species composition. Such changes in ecosystem structure and function or in ecosystem productivity may be undesirable if incompatible with management objectives. These subtle changes are evident only with long-term, relatively expensive monitoring of species abundance and biomass in addition to monitoring water chemistry.

NITROGEN SATURATION

Nitrogen saturation is defined for this report as the export of nitrogen from the system during times of the year when ecosystem biota should be taking up all available nitrogen for growth. Export indicates that more nitrogen is present in the system than can be used by the biota; excess nitrogen is detected in surface waters. This generally occurs during August and early September (Musselman 1994, Williams 1994) after most snowmelt has ceased and temperatures are optimum for production. Nitrogen saturation, as commonly defined, suggests the existence of maximum possible biota use, which indicates that growth is not limited by nitrogen. However, as discussed, other factors can cause export before the point of maximum productivity is reached.

Nitrogen saturation can have major impacts on terrestrial ecosystems such as changes in productivity and species composition and increased winter damage (Aber et al. 1989). There can be modifications in above-ground and below-ground biodiversity as the growth and survival of certain species are favored over others. Terrestrial ecosystems with sufficient nitrate input can be limited by other nutrients, such as phosphorus, resulting in nitrate export. Soils most at risk to increased nitrogen are those with low: 1) cation exchange capacity, 2) base saturation, 3) clay or organic matter content, 4) sulfate and nitrate adsorption capacity, and those with a pH range of 5.5 to 6.5 (Smith 1992). These are characteristics typical of high-elevation soils.

Excess nitrogen input from deposition or from weathering may be historically common at specific seasonal time periods. However, if the nitrogen input is higher than historic levels, particularly during periods of peak seasonal nitrogen use by biota, ecosystem processes may be altered by the additional nitrogen.

Recent research indicates that some Colorado Front Range aquatic ecosystems are near or above the saturation point for nitrogen deposition (Williams et al. 1993, 1996). High-elevation alpine aquatic ecosystems are the most susceptible to excess nitrogen (Baron et al. 1994). Small catchments with young, shallow soils, large amounts of exposed, slowly weatherable, quartz or quartzite bedrock, and steep terrain are particularly susceptible to saturation.

METHODS

High-elevation lakes and first order streams in catchments with a high percentage of exposed bedrock or glaciated landscape were selected for sampling (table 1). Most of the lakes sampled are in the Arapaho and Roosevelt National Forests covering the northern part of Colorado's Front Range. Some lakes sampled in the Western Lake Survey (Eilers et al. 1987) were resurveyed.

Lakes were sampled at or near the outlet. Inlet streams were sampled at a point as near as possible to lake entry. If there was more than one inlet stream, one was selected in catchments with steep terrain, few meadows, an abundance of rock outcrops, and little soil development. These streams generally had rapid flow through distinct channels in rocky areas rather than meadows. They were likely to become nitrogen saturated

Table 1. Water chemistry for lakes and streams sampled.

Wilderness Or other location	Site - Lake or stream	Inlet/ outlet	Date	pH	Conduct. µs/cm	ANC µeq/l	Ca^{++} µeq/l	Mg^{++} µeq/l	Na^{+} µeq/l	K^{+} µeq/l	NH_4^{+} µeq/l	Cl^{-} µeq/l	NO_3^{-} µeq/l	$SO_4^{=}$ µeq/l
Colorado State Forest	Clear Lake	Outlet	09/11/95	6.91	27.59	240.80	198.71	33.73	38.24	17.52	2.49	3.47	1.18	33.10
Colorado State Forest	Kelly Lake	Outlet	09/10/95	6.90	18.11	194.80	159.09	35.93	24.94	9.45	1.59	2.17	0.00	26.30
Colorado State Forest	Kelly Lake	Outlet	08/02/95	6.58	25.09	187.20	151.97	41.56	22.46	8.59	0.89	1.40	2.02	26.22
Colorado State Forest	Ruby Jewel Lake		08/01/95	6.63	29.27	228.80	184.56	59.88	21.85	8.30	0.00	1.66	15.81	21.09
Colorado State Forest	Ruby Jewel Lake	Inlet	09/09/95	7.09	37.06	382.80	340.38	69.80	37.25	10.66	2.30	1.64	5.00	33.79
Eagles Nest	Lost Lake South		08/25/95	6.91	14.51	166.50	88.85	46.77	35.41	7.05	1.35	1.41	0.00	10.76
Eagles Nest	Lost Lake South Dup		08/25/95	6.62	14.49	166.20	86.70	46.37	35.18	6.80	1.14	0.80	0.00	9.62
Eagles Nest	Uneva Pass Lake		08/25/95	7.43	56.52	612.30	354.09	346.12	35.76	13.69	1.10	1.30	11.71	42.68
Holy Cross	Blodgett Lake		09/04/95	6.65	7.02	61.50	47.46	11.62	7.69	2.31	0.00	1.55	0.00	9.40
Holy Cross	Booth Lake		09/25/95	6.54	9.54	103.30	66.07	41.88	11.87	4.65	0.28	1.57	0.59	8.48
Holy Cross	Missouri Lake		08/06/95	6.40	11.93	110.50	77.27	37.13	9.44	3.72	0.00	0.72	3.71	15.40
Holy Cross	Savage Lake (Upper)		07/18/95	5.98	8.81	63.80	53.66	22.28	13.68	4.78	0.00	1.30	3.19	9.47
Holy Cross	Strawberry Lake		08/26/95	6.78	17.52	110.20	282.60	33.91	14.84	6.72	0.00	0.46	5.96	65.78
Holy Cross	Tuhare Lakes		08/07/95	6.44	11.72	111.60	97.26	22.42	9.77	3.83	1.11	2.27	6.37	18.38
Indian Peaks	Blue Lake	Outlet	08/04/95	5.64	6.82	20.60	35.83	6.75	9.40	2.10	0.67	1.60	12.56	19.56
Indian Peaks	Blue Lake	Outlet	09/04/95	5.95	5.80	23.90	30.05	0.00	9.40	0.00	0.00	0.71	7.10	17.12
Indian Peaks	Blue Lake *	Inlet	07/11/95	5.73	6.20	8.12	36.73	6.42	11.44	2.40	1.11	1.61	20.85	20.02
Indian Peaks	Blue Lake *	Outlet	07/11/95	6.14	9.20	28.18	58.63	9.62	15.05	3.53	1.55	2.20	17.48	29.85
Indian Peaks	Blue Lake Talus *		07/11/95	6.98	20.70	130.20	174.65	19.25	25.92	2.25	0.18	2.51	17.08	48.74
Indian Peaks	Caribou Lake *	Inlet	07/31/95	7.23	25.80	253.83	152.89	133.10	21.84	5.70	0.01	1.41	15.26	17.77
Indian Peaks	Caribou Lake *	Inlet	07/31/95	6.99	19.03	155.42	112.23	58.74	27.93	7.01	0.00	1.68	8.31	22.75
Indian Peaks	Caribou Lake *	Inlet	07/31/95	6.99	18.26	144.00	118.96	57.01	29.71	7.01	0.00	1.92	13.21	23.85
Indian Peaks	Caribou Lake *	Inlet	07/31/95	7.03	16.90	150.07	67.61	101.02	4.52	5.70	0.20	0.79	3.73	3.33
Indian Peaks	Caribou Lake *	Outlet	07/31/95	7.15	27.40	219.95	149.90	88.85	26.10	6.29	1.03	1.52	3.97	24.73
Indian Peaks	Columbine Lake*	Inlet	07/31/95	6.89	9.41	79.42	59.38	22.29	24.31	2.92	0.00	1.33	3.02	10.48
Indian Peaks	Columbine Lake *	Inlet	07/31/95	7.23	21.80	184.98	161.88	64.25	20.75	8.47	0.31	2.20	17.95	17.87
Indian Peaks	Columbine Lake *	Outlet	07/31/95	7.02	14.70	112.35	93.81	36.28	17.88	5.27	0.28	1.61	7.81	13.06
Indian Peaks	Crater Lake	Inlet	08/07/95	6.08	6.78	41.50	42.32	6.75	6.31	1.25	0.39	1.29	5.15	11.38
Indian Peaks	Crater Lake	Outlet	08/07/95	6.11	8.50	51.70	53.44	7.49	7.31	1.69	0.39	1.69	4.05	14.59
Indian Peaks	Crater Lake	Inlet	09/16/95	6.46	7.88	57.40	62.84	6.98	9.22	1.70	0.00	2.68	0.46	11.46
Indian Peaks	Crater Lake	Outlet	09/16/95	6.43	6.89	57.40	63.03	6.17	6.85	1.08	0.00	1.11	0.00	11.29
Indian Peaks	Crater Lake *	Inlet	08/11/95	6.53	10.62	53.29	85.43	5.18	8.48	1.97	0.15	1.21	12.71	13.41
Indian Peaks	Crater Lake *	Outlet	08/11/95	6.56	8.10	49.22	63.37	6.09	7.79	1.69	0.53	1.27	3.77	14.12
Indian Peaks	Dorothy Lake *	Inlet	08/07/95	6.24	6.90	19.09	34.03	9.38	6.35	3.17	0.46	2.59	8.10	12.50
Indian Peaks	Dorothy Lake *	Outlet	08/07/95	6.41	6.40	32.46	40.92	11.43	6.70	3.68	1.26	2.06	6.69	14.62
Indian Peaks	Gourd Lake *	Inlet	08/19/95	7.30	31.80	208.44	189.12	96.00	40.71	7.03	1.07	3.05	17.01	73.70
Indian Peaks	Gourd Lake *	Inlet	08/19/95	7.23	38.40	171.23	268.11	72.97	33.75	2.66	0.44	0.42	0.00	157.47
Indian Peaks	Gourd Lake *	Inlet	08/19/95	7.63	55.60	305.07	361.63	140.18	51.15	6.47	0.88	1.95	2.50	198.30
Indian Peaks	Isabelle Lake *	Inlet	07/08/95	6.25	9.40	31.58	60.33	9.46	14.31	4.22	0.61	2.00	15.42	31.52
Indian Peaks	Island Lake	Outlet	08/11/95	6.44	15.44	119.50	95.53	29.36	19.96	1.37	0.00	2.99	8.51	37.01
Indian Peaks	Island Lake	Inlet	09/07/95	6.27	9.27	79.10	70.35	17.32	10.91	1.01	0.00	0.27	5.85	14.86
Indian Peaks	Island Lake	Outlet	09/07/95	6.62	12.15	108.10	93.87	25.30	17.23	1.59	0.99	0.85	0.00	29.16
Indian Peaks	Island Lake *	Inlet	08/19/95	7.09	15.40	121.90	124.55	22.13	15.66	3.25	0.57	1.02	4.74	17.02
Indian Peaks	Island Lake *	Inlet	08/19/95	6.86	10.90	79.13	76.70	18.76	12.88	2.53	0.73	0.82	7.73	14.52
Indian Peaks	King Lake	Outlet	09/17/95	6.27	7.62	54.40	320.56	20.90	19.23	3.71	1.05	2.06	0.00	18.05
Indian Peaks	King Lake *	Inlet	07/24/95	6.05	3.63	18.19	23.10	4.36	7.44	1.13	0.00	0.96	1.94	8.81
Indian Peaks	King Lake *	Inlet	07/24/95	6.05	4.50	20.93	16.92	5.10	16.49	3.22	2.33	1.47	8.34	6.56
Indian Peaks	King Lake *	Outlet	07/24/95	6.16	8.58	42.91	46.73	14.73	17.96	4.50	1.17	2.62	6.66	19.35
Indian Peaks	Long Lake	Inlet	09/10/95	6.58	13.33	129.30	114.42	25.02	15.93	1.45	0.94	0.67	0.00	23.91

Table 1. Cont'd.

Wilderness Or other location	Site - Lake or stream	Inlet/ outlet	Date	pH	Conduct. µs/cm	ANC µeq/l	Ca^{++} µeq/l	Mg^{++} µeq/l	Na^{+} µeq/l	K^{+} µeq/l	NH_4^{+} µeq/l	Cl^{-} µeq/l	NO_3^{-} µeq/l	$SO_4^{=}$ µeq/l
Indian Peaks	Long Lake	Outlet	09/10/95	6.54	15.85	147.60	139.94	28.18	19.31	1.64	1.11	0.84	0.51	32.78
Indian Peaks	Lower Coney Lake*		08/03/95	7.07	17.40	91.31	139.42	16.29	16.09	4.25	1.21	2.12	8.82	49.91
Indian Peaks	Lower Storm Lake*	Inlet	08/07/95	6.86	10.90	61.59	67.91	27.39	10.27	3.89	0.00	1.97	15.13	14.25
Indian Peaks	Lower Storm Lake *	Inlet	08/07/95	6.57	5.40	38.21	41.32	11.43	14.18	2.28	0.00	1.27	5.85	14.06
Indian Peaks	Lower Storm Lake *	Outlet	08/07/95	6.95	9.40	70.20	74.00	23.03	14.53	3.89	0.09	1.61	9.48	16.48
Indian Peaks	No Name Lake	Outlet	09/17/95	6.10	6.19	27.00	35.53	12.51	8.53	2.74	0.00	1.96	11.48	8.74
Indian Peaks	No Name Lake Dup	Outlet	09/17/95	6.09	6.74	27.30	34.63	12.34	9.74	3.04	0.00	1.66	11.40	9.30
Indian Peaks	Red Deer Lake	Inlet	08/07/95	6.36	10.85	76.80	70.11	21.56	18.05	2.94	0.67	2.28	4.14	25.01
Indian Peaks	Red Deer Lake	Outlet	08/07/95	6.36	12.58	76.70	66.97	21.56	15.31	3.81	0.67	3.24	3.58	25.05
Indian Peaks	Red Deer Lake	Outlet	09/10/95	6.40	9.81	80.50	76.21	21.47	13.98	1.23	0.00	0.88	0.00	23.50
Indian Peaks	Red Deer Lake *	Inlet	07/27/95	6.92	28.20	165.51	196.06	56.52	31.01	4.91	0.03	2.03	13.19	71.59
Indian Peaks	Red Deer Lake *	Inlet	07/27/95	6.08	5.94	24.00	27.89	8.06	13.96	1.84	0.00	1.38	6.56	11.33
Indian Peaks	Red Deer Lake *	Inlet	07/27/95	6.63	11.49	68.37	74.10	19.25	19.75	2.53	0.00	1.27	6.55	25.54
Indian Peaks	Red Deer Lake *	Outlet	07/27/95	6.57	11.95	78.29	81.59	21.96	18.31	2.81	0.00	1.66	5.79	25.91
Indian Peaks	Round Lake	Outlet	08/03/95	5.96	6.85	41.50	41.02	12.67	10.44	4.22	0.39	1.17	6.62	12.16
Indian Peaks	Round Lake	Outlet	09/04/95	6.22	6.13	47.40	37.20	6.25	12.06	0.00	0.00	0.96	1.13	12.10
Indian Peaks	Stone Lake	Outlet	08/07/95	6.35	10.43	73.60	65.42	17.44	10.44	2.10	0.39	1.74	3.13	17.07
Indian Peaks	Stone Lake	Outlet	09/03/95	6.53	10.50	92.20	70.84	13.78	12.02	0.00	0.00	0.00	0.99	19.17
Indian Peaks	Triangle Lake*	Inlet	08/11/95	6.18	4.67	26.94	30.99	2.88	5.31	2.86	0.12	0.96	9.55	5.60
Indian Peaks	Triangle Lake *	Inlet	08/11/95	5.89	3.63	11.13	20.66	2.06	2.83	1.69	0.93	1.18	8.74	5.17
Indian Peaks	Triangle Lake *	Outlet	08/12/95	6.74	12.75	70.90	102.15	6.75	12.74	3.17	0.09	1.35	16.34	20.73
Indian Peaks	Upper Coney Lake*	Inlet	08/03/95	7.00	16.80	116.26	161.13	12.42	11.79	4.09	0.14	1.27	15.16	39.85
Indian Peaks	Upper Coney Lake *	Inlet	08/03/95	6.77	9.20	59.62	85.58	7.24	10.00	2.92	0.00	1.49	12.40	25.14
Indian Peaks	Upper Coney Lake *	Outlet	08/03/95	6.97	11.70	71.63	102.79	8.97	12.14	3.81	1.27	1.64	9.48	36.45
Indian Peaks	Upper Diamond Lake*	Outlet	08/07/95	6.99	13.20	82.38	76.30	38.25	10.96	4.19	0.00	1.38	16.18	14.41
Indian Peaks	Upper Lake	Outlet	08/08/95	6.38	14.67	87.90	76.50	22.46	11.00	2.10	0.39	0.92	4.77	20.37
Indian Peaks	Upper Lake	Inlet	09/03/95	6.33	8.42	66.90	56.27	6.56	10.64	0.00	0.00	0.32	0.91	15.73
Indian Peaks	Upper Lake	Outlet	09/03/95	6.27	8.45	49.10	61.25	11.68	11.71	0.00	0.00	0.83	1.97	15.82
Indian Peaks	Upper Storm Lake*	Outlet	08/07/95	6.60	9.70	43.93	63.12	25.17	8.48	3.89	0.00	1.37	20.05	15.39
Indian Peaks	Watanga Lake	Inlet	08/10/95	6.52	13.22	137.00	82.14	23.07	57.14	1.68	0.84	1.19	0.26	12.01
Indian Peaks	Watanga Lake	Outlet	08/10/95	6.51	13.01	128.40	73.18	23.96	56.89	2.76	0.00	1.77	0.00	13.01
Indian Peaks	Watanga Lake	Inlet	09/14/95	6.76	15.03	156.10	106.39	28.58	0.00	2.30	4.82	1.53	0.00	16.59
Indian Peaks	Watanga Lake	Outlet	09/14/95	6.78	14.30	149.10	100.09	27.15	65.25	1.79	4.70	10.64	0.00	21.03
Indian Peaks	Watanga Lake *	Inlet	08/20/95	7.57	16.30	120.77	90.02	23.28	59.72	3.09	0.44	1.38	2.45	16.37
Indian Peaks	Watanga Lake *	Inlet	08/20/95	7.30	15.90	142.79	101.15	22.95	56.15	2.38	1.76	1.21	0.00	12.48
Indian Peaks	Watanga Lake *	Outlet	08/20/95	7.33	14.40	113.03	77.79	21.64	54.02	2.38	0.01	0.96	0.00	14.14
Indian Peaks	Watanga Area Stream *		08/20/95	6.93	10.20	65.50	64.42	12.18	26.10	2.22	0.34	1.21	4.52	16.18
La Garita	U-Shaped Lake		09/19/95	6.56	12.81	111.20	94.16	29.29	30.75	4.58	0.00	4.45	3.07	19.86
Loveland Pass	Loveland Pass Stream *		08/02/95	7.32	27.70	261.42	207.53	80.78	36.89	8.31	0.55	1.72	4.92	43.20
Loveland Pass	Loveland Pass Stream *		08/02/95	7.02	17.90	116.83	101.30	23.77	46.59	7.19	0.00	2.65	7.84	15.87
Loveland Pass	Loveland Pass Stream *		08/02/95	7.52	32.00	353.47	235.93	145.44	21.84	6.29	0.00	2.34	2.44	13.41
Medicine Bow NF	Long Lake	Outlet	09/18/95	6.66	28.78	236.20	174.05	106.07	42.71	8.41	1.33	4.22	0.67	19.59
Medicine Bow NF	Lost Lake - GLEES	Inlet	09/18/95	6.52	10.88	78.60	70.96	41.64	13.88	6.47	0.28	2.41	0.99	33.63
Medicine Bow NF	Lost Lake - GLEES	Outlet	09/18/95	6.64	7.28	54.00	47.31	26.58	10.05	4.42	0.00	2.18	0.00	18.55
Medicine Bow NF	North Twin Lake	Outlet	09/18/95	7.97	15.50	153.50	127.15	34.48	24.27	16.04	0.44	4.19	0.00	22.34
Medicine Bow NF	South Twin Lake	Inlet	09/18/95	6.84	17.26	193.90	156.19	48.06	26.71	8.75	0.00	1.85	0.00	14.12
Medicine Bow NF	South Twin Lake	Outlet	09/18/95	6.73	12.69	139.00	117.51	37.77	19.31	3.96	0.00	0.66	0.00	11.34
Medicine Bow NF	West Glacier Lake - GLEES	Inlet	08/11/95	5.43	3.40	3.20	18.39	5.25	2.77	0.00	0.00	0.90	7.23	4.92
Medicine Bow NF	West Glacier Lake - GLEES	Outlet	08/11/95	5.96	5.30	34.50	33.56	14.72	6.17	1.45	0.00	1.59	0.00	10.20

Table 1. Cont'd.

Wilderness Or other location	Site - Lake or stream	Inlet/ outlet	Date	pH	Conduct. µs/cm	ANC µeq/l	Ca^{++} µeq/l	Mg^{++} µeq/l	Na^{+} µeq/l	K^{+} µeq/l	NH_4^{+} µeq/l	Cl^{-} µeq/l	NO_3^{-} µeq/l	$SO_4^{=}$ µeq/l
Medicine Bow NF	West Glacier Lake - GLEES	Inlet	09/14/95	5.50	2.82	4.40	9.03	4.44	2.96	2.15	0.00	0.61	6.25	4.42
Medicine Bow NF	West Glacier Lake - GLEES	Outlet	09/14/95	6.22	5.03	39.90	35.78	15.63	7.57	1.92	1.11	1.27	0.00	10.75
Mount Evans	Abyss Lake		08/04/95	6.73	12.70	101.90	89.17	17.03	16.96	8.08	0.39	3.14	10.04	26.27
Mount Evans	Abyss Lake		09/13/95	6.83	11.97	91.30	93.43	13.82	19.72	7.16	0.87	2.96	7.00	28.84
Mount Evans	Abyss Lake		10/04/95	6.42	12.12	95.90	94.65	13.98	20.51	7.09	0.00	3.12	5.69	31.49
Mount Evans	Abyss Lake Dup		10/04/95	6.43	12.81	97.50	83.79	12.70	21.62	7.46	0.00	4.31	5.82	32.38
Mount Evans	Chicago Lake*	Inlet	08/02/95	7.04	28.60	164.29	200.05	43.02	36.15	9.64	0.30	1.89	12.87	58.16
Mount Evans	Chicago Lake *	Inlet	08/02/95	6.73	15.50	81.69	115.52	16.78	15.01	8.75	0.00	2.26	23.24	31.95
Mount Evans	Chicago Lake *	Outlet	08/02/95	7.08	24.10	151.18	194.06	34.14	27.93	12.84	1.31	3.33	8.95	56.76
Mount Evans	Frozen Lake		08/04/95	6.34	11.92	94.20	90.82	20.90	10.79	7.21	0.00	2.13	12.56	16.35
Mount Evans	Frozen Lake		09/13/95	6.54	11.53	97.60	97.50	18.25	13.17	6.66	0.00	2.63	6.12	18.35
Mount Evans	Frozen Lake		10/05/95	6.43	11.66	100.80	88.53	17.37	13.33	6.07	0.00	1.91	4.78	20.69
Mount Evans	North Lake		08/07/95	6.33	12.37	113.40	105.59	27.90	11.83	3.79	1.39	10.13	0.31	18.61
Mount Evans	North Lake		09/13/95	6.56	13.33	111.30	138.02	28.73	1.15	0.00	0.00	1.77	0.24	26.95
Mount Evans	South Lake		08/07/95	6.21	9.83	65.90	79.24	20.00	6.70	6.37	0.00	2.04	16.21	15.95
Mount Evans	South Lake		09/13/95	6.55	18.46	117.00	159.64	33.39	13.26	8.85	0.00	3.54	41.40	40.55
Mount Evans	South Lake Dup		09/13/95	6.63	18.65	118.20	162.22	33.60	13.24	8.88	0.00	3.57	38.46	40.55
Mount Evans	Summit Lake*	Inlet	08/02/95	6.86	14.10	82.46	95.31	27.81	21.44	7.60	0.00	1.89	14.34	20.18
Mount Evans	Summit Lake *	Outlet	08/02/95	6.89	14.64	97.75	104.29	20.57	25.75	10.20	0.56	3.07	4.44	29.81
Mount Evans	Upper Middle Beartrack Lake		09/10/95	6.32	9.57	59.60	55.85	19.69	13.33	14.86	1.03	4.30	0.00	17.08
Mount Evans	Upper Middle Beartrack Lake Dup		09/10/95	6.06	9.23	56.70	54.75	19.64	14.38	15.39	0.00	6.17	0.00	17.30
Mount Evans	Upper Middle BeartracksLake		08/05/95	6.45	9.58	67.60	65.77	25.18	13.09	14.96	0.22	3.85	0.36	14.85
Niwot Ridge	Long Lake Valley Stream *		07/08/95	6.54	21.30	125.48	186.98	33.23	48.02	7.60	0.65	4.68	11.68	94.98
Niwot Ridge	Long Lake Valley Stream *		07/08/95	6.33	20.90	125.98	147.41	24.76	15.40	9.28	0.60	3.38	1.68	52.97
Niwot Ridge	Long Lake Valley Stream *		07/08/95	6.69	13.40	95.81	117.86	16.62	20.14	7.60	0.86	3.75	16.17	26.38
Niwot Ridge	Long Lake Valley Stream *		07/08/95	6.80	17.80	88.01	134.88	14.40	24.49	8.00	0.33	3.41	14.77	44.53
Niwot Ridge	Niwot *		07/07/95	6.00	12.58	66.62	70.61	23.28	41.89	9.69	0.19	3.95	0.00	44.70
Niwot Ridge	Niwot *		07/07/95	6.39	7.92	36.40	45.76	9.79	11.44	2.81	1.93	1.64	11.16	9.60
Niwot Ridge	Niwot *		07/07/95	6.01	5.30	63.23	32.53	11.19	13.96	6.19	1.78	1.97	6.06	6.71
Niwot Ridge	Niwot *		07/07/95	6.20	19.80	65.56	128.14	35.54	50.50	11.53	0.01	11.59	0.00	77.72
Niwot Ridge	Niwot *		07/07/95	6.12	8.72	75.56	63.82	19.58	15.40	9.41	0.41	2.12	4.10	7.87
Rawah	Blue Lake	Outlet	08/02/95	6.51	18.74	160.00	123.35	36.80	32.32	6.61	0.00	2.27	6.28	24.68
Rawah	Blue Lake	Inlet	09/08/95	6.65	17.45	180.60	138.24	34.35	38.33	7.25	2.30	1.70	1.60	23.33
Rawah	Blue Lake	Outlet	09/08/95	6.71	17.73	185.40	141.84	35.23	39.48	7.55	2.38	1.80	1.13	26.03
Rawah	Camp Lake	Inlet	09/10/95	6.55	16.33	168.60	129.07	30.46	46.42	6.73	3.20	2.23	0.00	18.37
Rawah	Camp Lake	Outlet	09/10/95	6.60	17.50	179.90	137.12	32.22	48.26	6.37	3.28	1.53	0.00	17.76
Rawah	Carey Lake		08/06/95	6.40	12.04	94.00	79.74	17.44	13.40	5.06	0.67	1.86	13.82	13.67
Rawah	Carey Lake	Inlet	09/16/95	6.51	8.39	84.00	81.74	12.77	11.11	4.91	0.00	0.00	2.99	12.94
Rawah	Carey Lake	Outlet	09/16/95	6.70	11.65	120.40	106.36	19.64	16.61	4.74	0.00	0.00	1.54	12.71
Rawah	Carey Lake Area Inlet Stream *		08/15/95	7.34	17.00	163.04	167.56	26.08	18.44	6.85	0.00	1.38	16.08	13.52
Rawah	Carey Lake Area Inlet Stream *		08/15/95	5.99	2.40	18.39	14.47	2.39	3.87	1.97	0.04	2.37	4.37	2.37
Rawah	Carey Lake Area Inlet Stream *		08/15/95	6.49	5.30	41.55	40.62	6.25	4.22	1.53	0.00	1.35	11.82	5.50
Rawah	Carey Lake Area Inlet Stream *		08/15/95	5.55	2.20	12.87	4.84	1.40	6.00	0.79	0.34	1.02	2.98	1.65
Rawah	Hang Lake	Outlet	08/02/95	6.39	18.46	114.70	99.80	20.52	20.93	4.11	0.00	1.97	6.80	15.18
Rawah	Hang Lake	Inlet	09/08/95	6.55	12.67	131.50	107.42	18.10	24.91	5.03	1.40	1.14	0.57	14.13
Rawah	Hang Lake	Outlet	09/08/95	6.56	12.92	131.30	105.86	17.65	24.78	4.97	1.42	1.04	0.27	14.05
Rawah	Iceberg Lake	Outlet	08/06/95	6.04	9.25	44.40	52.06	8.89	12.88	3.81	0.67	1.92	16.97	14.17
Rawah	Iceberg Lake	Outlet	09/17/95	6.71	7.33	53.60	56.58	9.05	14.14	3.18	0.00	0.00	8.04	13.77
Rawah	Island Lake	Outlet	08/06/95	6.21	9.86	67.60	60.83	11.19	10.18	5.50	0.67	3.75	6.64	15.33

Table 1. Cont'd.

Wilderness Or other location	Site - Lake or stream	Inlet/ outlet	Date	pH	Conduct. µs/cm	ANC µeq/l	Ca^{++} µeq/l	Mg^{++} µeq/l	Na^{+} µeq/l	K^{+} µeq/l	NH_4^{+} µeq/l	Cl^{-} µeq/l	NO_3^{-} µeq/l	$SO_4^{=}$ µeq/l
Rawah	Island Lake	Outlet	09/16/95	6.67	7.52	70.00	60.81	9.25	8.83	4.74	0.00	0.00	0.00	11.18
Rawah	Island Lake Dup	Outlet	08/06/95	6.22	9.45	67.70	59.33	10.37	8.87	5.50	0.39	2.67	6.07	11.37
Rawah	Little Rainbow Lake*	Inlet	08/16/95	7.00	13.00	120.57	103.39	18.92	37.93	5.58	0.00	1.41	5.40	11.64
Rawah	Little Rainbow Lake*	Inlet	08/16/95	6.97	10.50	74.92	64.42	16.12	28.53	3.25	0.86	1.38	6.82	11.79
Rawah	Lost Lake	Outlet	08/06/95	6.44	18.25	137.30	103.84	41.80	51.89	5.91	1.55	4.94	0.00	29.15
Rawah	Lost Lake	Outlet	09/09/95	6.59	19.02	173.90	127.50	43.69	93.87	4.72	6.20	1.99	0.00	28.63
Rawah	Lower Camp Lake	Outlet	08/13/95	6.63	16.24	158.10	108.44	29.38	39.91	6.67	0.00	2.12	0.00	17.84
Rawah	Lower Sandbar Lake	Outlet	08/06/95	6.48	15.11	139.60	95.01	26.66	31.71	6.78	0.67	1.49	0.59	15.29
Rawah	Lower Sandbar Lake	Inlet	09/15/95	6.90	16.92	192.50	147.77	33.24	43.65	8.70	2.46	1.24	0.00	15.60
Rawah	Lower Sandbar Lake	Outlet	09/15/95	6.88	16.19	181.00	139.69	32.27	42.65	7.46	2.36	0.96	0.00	15.16
Rawah	Lower Twin Crater Lake		08/06/95	6.36	12.58	94.00	79.74	15.88	18.88	6.34	0.39	2.16	12.75	18.86
Rawah	Lower Twin Crater Lake	Inlet	09/16/95	6.65	11.52	110.30	99.81	16.46	21.04	6.49	0.89	0.00	4.37	17.97
Rawah	Lower Twin Crater Lake	Outlet	09/16/95	6.63	11.02	108.80	93.84	15.70	21.34	6.35	0.88	0.00	0.00	18.13
Rawah	Lower Twin Crater Lake	Outlet	08/06/95	6.95	17.24	166.10	105.64	33.74	49.80	4.65	1.22	3.33	0.00	24.17
Rawah	Lower Twin Crater Lake	Inlet	09/17/95	6.70	17.05	184.40	133.05	32.15	60.16	7.71	4.02	0.00	0.00	24.77
Rawah	Lower Twin Crater Lake	Outlet	09/17/95	6.84	18.16	198.20	143.49	36.64	89.30	7.60	4.50	0.00	0.00	24.33
Rawah	McIntyre Lake	Outlet	08/06/95	6.43	12.08	103.70	56.39	15.88	26.79	5.06	0.94	2.91	0.00	15.85
Rawah	McIntyre Lake	Inlet	09/17/95	6.53	11.28	113.80	87.29	17.72	34.63	6.98	1.71	0.00	0.38	14.38
Rawah	McIntyre Lake	Outlet	09/17/95	6.58	11.77	118.00	93.81	21.88	34.79	6.10	1.65	0.00	0.00	14.79
Rawah	Number 1 Lake	Outlet	08/06/95	6.36	11.25	95.00	65.42	20.74	23.97	6.78	0.67	2.31	4.59	15.16
Rawah	Number 1 Lake	Inlet	09/15/95	6.44	9.31	86.40	71.07	18.11	20.34	6.02	0.92	0.00	0.47	15.19
Rawah	Number 1 Lake	Outlet	09/15/95	6.56	10.90	103.90	79.59	20.19	24.72	5.93	1.17	0.00	0.54	15.32
Rawah	Number 2 Lake	Outlet	08/06/95	6.28	10.72	82.90	65.42	20.74	19.44	6.78	0.67	3.76	6.32	15.53
Rawah	Number 2 Lake	Inlet	09/15/95	6.55	9.10	86.80	70.19	17.59	19.67	6.10	0.85	0.00	1.06	14.70
Rawah	Number 2 Lake	Outlet	09/15/95	6.76	8.97	84.80	66.61	17.42	20.14	6.15	0.86	0.00	0.28	15.18
Rawah	Number 3 Lake	Outlet	08/05/95	6.31	10.37	77.10	60.83	19.91	17.79	7.19	0.67	2.27	8.48	14.85
Rawah	Number 3 Lake	Inlet	09/15/95	6.43	8.97	73.00	65.41	15.79	18.77	7.22	0.00	0.00	9.63	16.82
Rawah	Number 3 Lake	Outlet	09/15/95	6.55	8.99	84.60	61.06	16.00	18.62	6.15	0.00	0.00	0.83	17.86
Rawah	Number 3 Lake*	Inlet	08/16/95	6.83	9.20	61.80	68.86	6.91	16.70	4.42	0.44	0.34	2.26	16.33
Rawah	Number 3 Lake*	Inlet	08/16/95	6.75	7.70	65.55	56.64	11.93	20.18	4.86	0.00	1.33	9.66	12.50
Rawah	Number 4 Lake	Outlet	08/05/95	5.99	9.08	45.30	50.60	9.63	13.40	6.78	1.22	3.61	17.72	16.19
Rawah	Number 4 Lake	Inlet	08/15/95	7.21	18.71	137.33	159.18	11.11	23.75	9.95	0.44	2.06	16.45	15.83
Rawah	Number 4 Lake	Outlet	09/15/95	6.37	7.56	47.30	53.75	8.94	12.06	5.33	0.00	0.00	13.37	15.58
Rawah	Number 4 Lake Dup	Outlet	08/05/95	5.97	9.94	43.50	49.20	9.63	12.61	6.34	0.94	2.54	17.46	15.03
Rawah	Number 4 Lake*	Inlet	08/16/95	6.24	4.90	14.75	22.75	3.04	3.13	3.25	2.05	0.96	8.50	4.65
Rawah	Number 4 Lake*	Inlet	08/16/95	6.91	11.00	81.47	59.53	14.81	37.93	7.03	0.16	1.49	11.71	16.29
Rawah	Number 4 Lake*	Inlet	08/16/95	7.01	14.90	108.56	95.31	16.45	38.63	9.39	1.01	1.13	8.58	15.00
Rawah	Rocky Hole Lake*	Outlet	08/15/95	7.22	20.40	171.36	173.65	20.65	31.93	10.08	0.07	4.33	13.52	17.52
Rawah	Sugarbowl Lake	Outlet	08/06/95	6.46	11.16	96.80	66.97	15.06	25.66	6.78	0.67	3.04	4.61	13.53
Rawah	Sugarbowl Lake	Outlet	09/17/95	6.61	10.08	100.10	77.97	14.70	28.32	7.12	1.32	0.00	0.58	12.31
Rawah	Twin Crater Lake*	Inlet	08/15/95	6.95	10.40	80.32	58.03	15.96	26.92	7.14	0.27	1.61	7.37	9.85
Rawah	Twin Crater Lake*	Inlet	08/15/95	6.83	9.30	82.66	74.00	13.57	10.27	5.37	0.63	1.04	12.19	10.56
Rawah	Upper Camp Lake	Outlet	08/13/95	6.55	14.13	124.70	93.40	22.67	33.77	7.17	0.00	3.84	0.00	18.95
Rawah	Upper Camp Lake	Outlet	09/10/95	6.52	13.04	125.90	98.99	20.72	36.97	6.42	2.38	2.28	0.00	30.99
Rawah	Upper Sandbar Lake	Outlet	08/06/95	6.80	14.56	136.80	98.50	26.66	31.71	7.19	0.67	1.94	1.64	14.84
Rawah	Upper Sandbar Lake	Outlet	09/15/95	6.93	18.25	200.00	153.79	34.39	44.39	8.70	2.44	1.14	0.00	15.16
Rawah	Upper Twin Crater Lake		08/06/95	6.30	13.83	104.30	93.26	18.27	21.14	7.62	1.22	2.26	15.93	19.95
Rawah	Upper Twin Crater Lake	Outlet	09/16/95	6.68	11.60	110.60	100.65	16.38	21.02	6.58	0.91	0.00	4.23	18.22
Rawah	Upper Twin Lake	Outlet	08/06/95	6.91	12.82	120.50	88.12	18.27	32.28	6.34	0.67	2.06	0.00	19.64

Table 1. Cont'd.

Wilderness Or other location	Site - Lake or stream	Inlet/ outlet	Date	pH	Conduct. µs/cm	ANC µeq/l	Ca^{++} µeq/l	Mg^{++} µeq/l	Na^{+} µeq/l	K^{+} µeq/l	NH_4^{+} µeq/l	Cl^{-} µeq/l	NO_3^{-} µeq/l	$SO_4^{=}$ µeq/l
Rawah	Upper Twin Lake	Inlet	09/17/95	6.59	12.46	120.20	101.06	18.41	36.88	6.13	1.85	0.00	0.00	19.55
Rawah	Upper Twin Lake	Outlet	09/17/95	6.82	12.38	121.50	100.76	18.18	36.99	6.12	1.82	0.00	0.00	19.71
Sangre De Cristo	Banjo Lake		08/02/95	6.53	14.63	135.20	75.82	19.96	12.06	5.91	0.00	7.44	7.82	6.21
Sangre De Cristo	Banjo Lake Dup		08/02/95	6.56	15.76	136.40	113.17	9.95	18.44	6.69	2.45	11.86	7.70	9.06
Sangre De Cristo	Commanche Lake		07/25/95	7.21	62.55	556.90	426.15	196.50	36.32	9.69	1.11	3.44	5.59	112.73
Sangre De Cristo	Cotton Lake		07/31/95	7.56	162.00	1048.50	1361.68	611.36	37.39	8.51	2.54	5.68	28.92	176.40
Sangre De Cristo	Crater Lake		07/31/95	6.46	16.57	128.30	136.35	11.80	4.72	1.22	0.00	1.38	16.70	25.29
Sangre De Cristo	Deadman Lake		08/03/95	6.63	27.01	206.50	210.85	16.90	22.89	2.62	0.96	4.78	2.94	45.77
Sangre De Cristo	Dry Lake Upper		07/25/95	6.88	51.19	502.20	424.20	109.03	49.28	10.79	2.66	13.48	11.52	36.77
Sangre De Cristo	Dry Lake Upper Dup		07/25/95	6.90	50.45	493.60	411.33	108.78	28.49	6.85	1.44	3.92	10.24	31.81
Sangre De Cristo	Elaine Lake		07/28/95	6.80	27.17	248.90	196.19	17.40	16.73	2.50	2.04	2.78	0.94	13.35
Sangre De Cristo	Eureka Lake		07/25/95	7.14	74.45	554.80	636.73	222.67	24.32	9.69	1.11	2.64	21.21	258.03
Sangre De Cristo	Glacier Lake		08/02/95	6.67	8.37	79.70	47.63	8.50	11.85	5.16	0.00	2.01	0.35	11.02
Sangre De Cristo	Goodwin Lake		07/26/95	7.17	108.86	612.10	1127.66	273.64	47.23	23.95	0.55	4.12	17.03	562.79
Sangre De Cristo	Hermit Lake		07/25/95	7.24	118.73	761.20	364.20	23.16	9.25	0.46	0.00	3.70	6.48	526.77
Sangre De Cristo	Horn Lake		07/26/95	6.94	38.44	388.10	10.66	9.39	3.11	0.26	0.00	1.13	4.98	16.80
Sangre De Cristo	Horseshoe Lake		07/25/95	7.19	78.91	620.60	472.55	214.77	36.97	10.13	0.83	3.13	13.02	231.94
Sangre De Cristo	Hunts Lake		07/28/95	6.89	43.45	376.70	325.80	73.29	29.75	11.29	1.00	9.44	18.40	27.21
Sangre De Cristo	Hunts Lake Dup		07/28/95	6.92	42.02	374.10	323.97	72.73	22.37	8.37	0.00	2.18	18.53	27.20
Sangre De Cristo	Lilly Lake		07/25/95	7.01	53.42	467.50	11.45	11.10	8.99	0.50	0.00	4.21	12.91	89.30
Sangre De Cristo	Lilly Lake Dup		07/25/95	7.02	53.42	469.90	524.95	46.74	20.57	9.49	2.16	5.36	9.24	86.49
Sangre De Cristo	Lost Lake		08/02/95	6.83	30.50	272.80	231.16	24.41	13.86	2.78	0.98	0.52	3.86	11.64
Sangre De Cristo	Lost Lake Dup		08/02/95	6.82	30.40	271.70	227.88	23.69	14.50	3.03	0.00	0.92	3.88	11.94
Sangre De Cristo	Lower Brush Lake		08/01/95	7.48	70.18	673.90	598.80	87.97	33.20	21.04	1.25	10.23	0.41	68.35
Sangre De Cristo	Lower Bushnell Lake		08/02/95	7.35	31.42	267.00	177.84	98.50	11.35	6.26	0.00	1.95	5.53	21.22
Sangre De Cristo	Lower Little Sand Cr. Lake		08/03/95	6.62	18.35	153.40	131.28	18.49	19.96	3.42	1.35	2.81	0.00	44.66
Sangre De Cristo	Lower Sand Creek Lake		07/25/95	6.56	18.04	148.60	137.42	21.20	18.59	7.87	0.00	3.51	5.00	26.82
Sangre De Cristo	Macey Lake Middle		07/25/95	6.95	40.04	407.30	378.59	40.07	18.31	6.19	2.00	2.40	0.95	16.80
Sangre De Cristo	Macey Lake Upper		07/25/95	6.89	49.91	381.70	354.09	106.64	17.96	5.32	0.83	2.96	12.02	125.55
Sangre De Cristo	Mas Alto Lake		07/28/95	6.34	8.65	66.30	57.88	10.40	8.48	0.52	0.00	0.96	10.98	12.69
Sangre De Cristo	Medano Lake		07/27/95	6.62	29.68	229.60	190.08	35.08	25.75	6.24	0.00	2.28	17.11	20.17
Sangre De Cristo	Megan Lake		07/25/95	6.97	58.20	447.60	47.16	44.19	93.04	12.07	26.50	2.96	6.98	182.31
Sangre De Cristo	North Colony Lake		07/25/95	6.87	82.31	572.90	613.77	356.31	39.15	19.44	15.52	14.61	21.55	318.14
Sangre De Cristo	North Colony Lake Dup		07/25/95	6.94	82.20	569.10	1068.09	363.71	33.67	10.56	1.72	3.38	21.93	282.33
Sangre De Cristo	North Colony Lake Upper		07/25/95	7.08	79.12	757.80	365.74	71.61	12.02	7.24	0.89	2.26	15.03	139.23
Sangre De Cristo	North Crestone Lake		07/27/95	7.06	45.91	467.40	438.06	54.89	26.08	3.06	1.11	2.60	5.23	17.23
Sangre De Cristo	Rito Alto Lake		07/28/95	6.79	26.56	224.20	169.99	29.54	16.83	2.19	0.00	1.27	5.77	13.88
Sangre De Cristo	San Isabel Lake		07/27/95	6.93	39.90	391.40	348.24	31.55	19.34	2.51	0.95	2.20	4.38	10.80
Sangre De Cristo	Silver Lake		08/02/95	6.63	28.15	213.20	171.43	46.29	24.64	5.49	0.98	1.61	7.92	26.97
Sangre De Cristo	Small Lake Above U-Shaped Lake		08/03/95	6.26	7.29	53.70	37.36	9.78	8.90	0.00	0.00	1.97	0.00	8.34
Sangre De Cristo	Small Lake N of Medano		07/27/95	6.57	26.01	194.50	144.05	34.46	37.04	5.58	0.00	2.23	3.21	22.18
Sangre De Cristo	Small Lake S of Blue Lake		08/02/95	6.14	3.41	19.80	9.48	0.00	3.30	0.86	0.00	0.70	1.59	4.95
Sangre De Cristo	South Branch Lake		08/01/95	7.09	66.30	654.10	558.88	87.71	62.28	10.04	1.29	22.54	0.00	25.56
Sangre De Cristo	South Colony Lake		07/27/95	7.29	50.76	418.70	389.62	114.63	42.98	15.78	2.00	12.69	11.80	73.77
Sangre De Cristo	South Crestone Lake		07/26/95	6.97	40.50	406.20	367.65	32.46	16.77	2.26	4.99	1.59	0.28	12.24
Sangre De Cristo	Stout Creek Lake (Upper)		08/01/95	6.29	11.41	77.80	78.83	20.78	12.17	6.02	0.00	3.29	9.73	17.72
Sangre De Cristo	Stuart Creek Lake (Lower)		08/01/95	6.57	18.58	152.30	123.40	31.74	15.23	8.46	0.87	3.13	5.36	30.51
Sangre De Cristo	U-Shaped Lake		08/03/95	6.34	9.30	75.00	45.16	14.36	14.86	0.95	0.00	1.88	0.00	10.49
Sangre De Cristo	Unnamed Above Lilly Lake		07/25/95	7.03	49.81	466.70	575.85	33.82	17.96	10.13	2.00	3.81	17.19	43.47

Table 1. Cont'd.

Wilderness Or other location	Site - Lake or stream	Inlet/ outlet	Date	pH	Conduct. µs/cm	ANC µeq/l	Ca^{++} µeq/l	Mg^{++} µeq/l	Na^{+} µeq/l	K^{+} µeq/l	NH_4^{+} µeq/l	Cl^{-} µeq/l	NO_3^{-} µeq/l	$SO_4^{=}$ µeq/l
Sangre De Cristo	Upper Brush Lake		08/01/95	7.11	74.97	747.60	346.86	64.63	27.57	11.47	0.92	3.53	0.73	80.14
Sangre De Cristo	Upper Bushnell Lake		08/02/95	6.79	12.25	78.50	80.72	23.44	11.58	6.85	3.05	3.72	11.14	21.19
Sangre De Cristo	Upper Lake of The Clouds		07/26/95	7.26	121.49	787.40	1034.93	325.04	35.97	8.80	1.11	4.26	4.98	526.77
Sangre De Cristo	Upper Lake of The Clouds Dup		07/26/95	7.53	120.01	789.40	1043.91	329.15	34.80	9.90	8.87	3.38	11.77	519.69
Sangre De Cristo	Upper Little Sand Creek Lake		08/03/95	6.47	13.43	110.10	108.06	12.31	13.87	1.98	0.00	3.73	10.53	26.49
Sangre De Cristo	Upper Sand Creek Lake		07/25/95	7.01	28.18	195.10	187.36	25.78	17.19	5.80	1.03	2.97	4.58	37.02
Sangre De Cristo	Upper Willow Lake		07/26/95	6.73	27.27	223.40	184.07	31.52	7.76	1.03	0.00	1.41	16.43	11.57
Sangre De Cristo	Venable Lake Lower		07/25/95	6.79	33.24	267.50	188.82	84.67	46.32	19.72	4.10	19.41	0.00	40.29
Sangre De Cristo	Venable Lake Upper		07/25/95	6.74	36.85	313.70	227.69	105.33	39.97	12.30	2.94	8.72	2.97	52.53
Sangre De Cristo	West Creek Lake		08/01/95	6.25	12.42	65.80	61.92	25.07	25.56	9.64	1.15	9.18	10.35	26.04
Sangre De Cristo	Wild Cherry Lake		07/25/95	7.01	49.66	440.00	434.79	93.23	22.43	5.99	2.15	1.97	0.49	84.89
Sangre De Cristo	Wild Cherry Lake Dup		07/25/95	7.05	50.38	445.00	428.05	92.62	22.77	6.31	2.92	2.27	0.50	83.99
South San Juan	Glacier Lake		09/05/95	6.34	7.52	65.30	55.64	9.21	12.48	6.07	0.00	0.78	0.00	10.24
South San Juan	Small Lake S. of Blue Lake		09/05/95	5.90	4.16	26.20	21.86	3.04	6.44	3.91	0.00	0.00	0.00	5.98
South San Juan	Small Lake S. of Blue Lake		09/05/95	6.04	4.01	26.80	20.39	2.83	6.57	4.02	0.00	0.00	0.00	6.21
Weminuche	Lake Due South of Ute		08/05/95	5.94	5.30	31.30	33.40	13.99	4.11	3.29	0.00	18.79	0.00	7.82
Weminuche	Lake Due South of Ute		09/13/95	5.90	4.88	19.60	33.53	9.55	16.66	7.08	0.61	2.18	0.59	10.12
Weminuche	Lake Due South of Ute - Dup		08/05/95	6.29	5.36	32.20	33.11	14.02	5.75	10.26	0.00	56.88	0.00	8.23
Weminuche	Middle Ute Lake		08/08/95	6.12	6.81	43.80	44.11	21.16	5.45	1.95	0.00	9.54	0.00	15.24
Weminuche	Middle Ute Lake		09/13/95	6.21	7.94	41.90	43.71	18.19	8.31	1.46	3.55	2.08	4.28	17.28
Weminuche	Small Pond Above Trout Lake		08/05/95	6.20	3.64	24.10	19.47	7.55	3.41	2.13	0.00	1.55	0.00	2.75
Weminuche	Small Pond Above Trout Lake		08/11/95	6.08	4.79	26.90	23.60	7.32	9.40	4.27	0.00	2.16	0.61	7.50
Detection Limits, USFS, RMS Lab:							0.680	0.353	0.281	0.256	0.674	0.402	0.244	0.373

** water analysis by UC, all others analyzed by USFS, RMS Lab* because of limited opportunity for contact with soils of sufficient exchange capacity to retain nitrates.

The lakes and streams in the Rawah and Indian Peaks Wilderness areas were sampled for water chemistry in late July or early August. A second sample was collected in early September. If the system had detectible levels of nitrate in any of the samples, it was considered nitrogen saturated.

Although this study was a synoptic survey of lakes in Indian Peaks and Rawah Wilderness areas, data from additional lakes sampled during 1995 using the same protocols and the same sample collection window are also included in this report. These additional lakes are: five lakes in the Medicine Bow National Forest in southeastern Wyoming; 45 lakes and streams studied by the University of Colorado in the Indian Peaks and Rawah Wilderness areas in the Arapaho and Roosevelt National Forests; and approximately 80 lakes surveyed as synoptic or long-term monitoring in the Sangre De Cristo, Mt. Evans, Weminuche, South San Juan, La Garita, and Holy Cross Wildernesses in Colorado.

Sampling protocols

Sample collection followed precise protocols to avoid contamination and to standardize where and how samples were collected. Two training sessions were held before sampling to instruct field crews on the proper procedures. One lake water sample was collected from each site. An inlet-stream water sample was also collected if suitable inlets were present and access was possible for the Rawah Wilderness, Indian Peaks Wilderness, and Medicine Bow Mountain range lakes. The first sample was collected near the lake outlet and the second from a first order stream inlet to the lake. The sampling point was on the lake or stream edge on solid ground or rock to minimize water disturbance. Areas of wet or bog-type soil where foot pressure might disturb the lake or stream water were avoided. It was very important not to disturb the lake or stream bottom to avoid sample contamination. Plastic gloves, prewashed in distilled water, dried, and stored in zipped plastic bags, were worn during sample collection.

Samples were collected in 250 ml brown plastic bottles that were prewashed and filled with deionized water. They were emptied just before sampling. The bottles were labeled onsite using permanent markers with sample location, date, time, crew member names, and whether a lake or stream was sampled. Lake samples were collected as far from the shore as possible without disturbing the lake bottom. Stream samples were collected slightly upstream from the stream outlet as far into the stream as possible or at midstream if the stream was narrow. Bottles were rinsed three times with sample water then filled completely and capped. The samples were immediately placed in a small Styrofoam or thermal cooler containing a frozen icepack to keep them cold during transport. Protocols called for the collection of one duplicate sample from every 10th site and one deionized water field blank from every 20th site. Field blanks were unused, unemptied sample bottles taken to the field and returned unopened for analysis. Lakes chosen for duplicate samples were selected at random. Color photos were taken of the sample collection site and the surrounding landscape. A field data sheet containing lake, stream, watershed, and weather information was completed on site. Samples and field data sheets were shipped by overnight mail or hand delivered to the Rocky Mountain Forest and Range Experiment Station laboratory for chemical analysis. University of Colorado samples were analyzed in their laboratory.

Analyses

Samples were filtered (0.045 mm) in the laboratory and analyzed for cations (Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+) and anions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}) using ion chromatography. Sample pH, alkalinity, and conductivity were also determined in the laboratory. Data were examined for any unusual outlier of anions, cations, pH, alkalinity, or conductivity, and for ionic balances. A sample was considered nitrogen saturated if the nitrate concentration was 0.244 µeq/l or higher, which was the detection limit for the laboratory analytical methods at the Rocky Mountain Forest and Range Experiment Station laboratory.

RESULTS AND DISCUSSION

This study provides the most extensive database in existence regarding the chemical composition of high-elevation lakes and streams in the Front Range of the Rocky Mountains of Colorado and southeastern Wyoming (table 1). In addition, this study identifies lakes that might be susceptible to acidification and/or nitrogen loading from atmospheric deposition. The data presented here will be analyzed further to relate surface water chemistry to landscape characteristics. Lakes with very low ANC and high levels of nitrate will be further examined in follow up studies.

Most lakes examined in this study had low ANC (figure 1), suggesting sensitivity to acidification. More than 10% of the lakes were below 50 µeq/l ANC and can be considered very sensitive. The Sangre de Cristo Wilderness, where more than two-thirds of the lakes had greater than 200 µeq/l ANC, is an exception. However, 15% of the lakes in this Wilderness were below 100 µeq/l ANC and can be considered sensitive. Phosphate data are not presented because it was not detected in any of the lakes. This reflects the detection limit of the analysis rather than the presence or absence of phosphate. Variable levels of phosphate were likely present at low concentrations; phytoplankton population dynamics can respond to phosphate levels below the detection level of some analytical techniques.

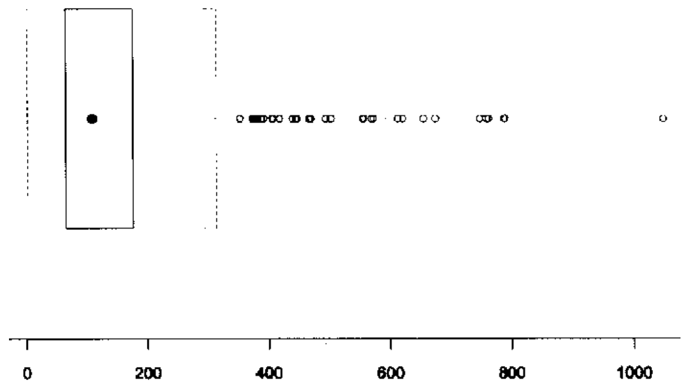

Figure 1. Statistical box plot of acid neutralizing capacity in µeq/l (micro equilvalents per liter) for lakes sampled in 1995. The solid rectangle is the range of 50% of the values; the dot is the median value; the dashed lines are the range of all observations; and the open circles are the outlier values.

There were detectable[1] levels of nitrate in many of the lakes (figure 2), suggesting that they could

[1] Some of the data presented in table 1 are below the determined detection limits. The reader should be aware of the uncertainty of those data. Detection limits were calculated following Environmental Protection Agency methods as "three times the standard deviation of 10 nonconsecutive reagent or calibration blank analyses" (EPA 1987).

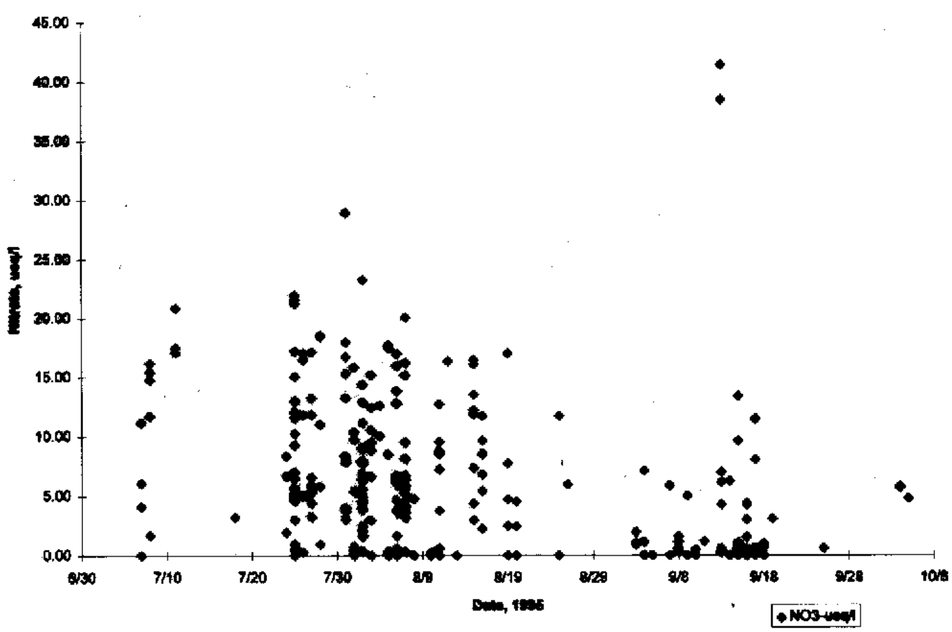

Figure 2. Nitrate concentration in wilderness lakes by sampling date.

be nitrogen saturated. Further experimentation is necessary to verify saturation. The data also show that samples collected early in the season had nitrate concentrations higher (figures 2 and 3) than those collected later in the season. The earlier samples were probably influenced by the late snowpack runoff. Nitrates were frequently higher in lake inlet streams to than outlet streams (figure 4). This may be a reflection of the shorter residence time in streams versus lakes and the decreased opportunity for exchange in streams with soil and biota compared to lakes.

Chemical composition will be correlated with catchment physical characteristics in future manuscripts. Landscape habitat and soil type were identified from topographic and soils maps and were field verified. The data will be stratified and analyzed by latitude/longitude, elevation, geology, soil type, terrain features, and landscape characteristics to determine if these factors influence nitrogen saturation. Sites with particularly low ANC and particularly high nitrate levels will be resampled for water chemistry at more frequent intervals, and sampled for phytoplankton species and biomass to verify timing, extent, and source of any possible saturation. Further analyses will be

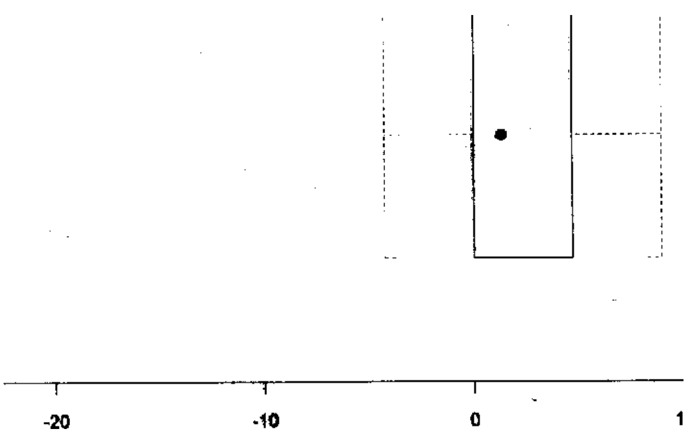

Figure 3. Box plot of nitrate concentration in µeq/l (micro equilvalents per liter) for lakes sampled in 1995 comparing the difference between early and late sampling dates (early minus late). The solid rectangle is the range of 50% of the values; the dot is the median value; and the dashed lines are the range of all observations.

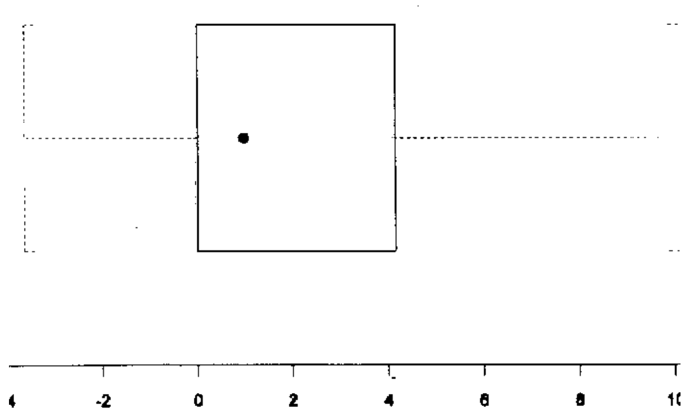

Figure 4. Box plot of nitrate concentration in µeq/l (micro equilvalents per liter) for lakes sampled in 1995 comparing difference between lake inlets and outlets (inlet minus outlet). The solid rectangle is the range of 50% of the values; the dot is the median value; and the dashed lines are the range of all observations.

conducted to compare stream versus lake data for nitrate content. Phosphorus concentrations also will be closely monitored.

Changes in nitrogen input to wilderness ecosystems can affect the nutrient balance and species assemblages of these systems. High-elevation mountainous aquatic ecosystems in the Front Range are particularly sensitive to these changes. Understanding the susceptibility and response of aquatic ecosystems to the direct input of atmospheric deposition is important for wilderness managers maintaining ecosystems for future use. The data from this study provide information on the impact of pollutants from point sources that are located near wilderness areas.

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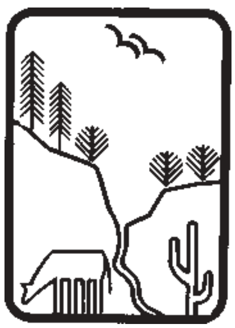
ACKNOWLEDGMENTS

This study was initiated as a cooperative effort between the Arapaho and Roosevelt National Forests and the Rocky Mountain Forest and Range Experiment Station. The National Forest was interested in a synoptic study of high-elevation lake water chemistry and the Research Station was interested in sensitivity of high-elevation lakes to atmospheric deposition. The University of Colorado has been studying water nitrogen saturation in Front Range aquatic ecosystems. A study plan was written and approved by USDA Forest Service researchers. Sample analyses for most lakes were funded by the respective National Forests or by Forest Service Research. The University of Colorado funded their sample analyses. We gratefully acknowledge the assistance of the volunteers who attended sample collection training and collected the water and stream samples for this study. We acknowledge personnel in the Rocky Mountain Forest and Range Experiment Station Water Analysis Laboratory who filtered and analyzed the National Forest and Forest Service Research samples. We thank Christi Gordon, Leslie Dobson, and Andrea Sears for use of data from their National Forests in this report. We acknowledge Jill Baron, National Biological Service, for assisting in one of the sample collection training sessions. We are particularly grateful to students Tim Platt-Mills, University of Colorado at Boulder and Yale University, who collected the University of Colorado samples, and Darrel Jury, Colorado State University, who compiled the list of Arapaho and Roosevelt National Forests Wilderness lakes to sample and assisted in sample collection and data compilation. We thank Rudy King for advice and assistance with data analysis.

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains



Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota

*Station Headquarters: 240 W. Prospect Rd., Fort Collins,CO 80526